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A Plasma Rocket Demonstration on the International Space Station

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Development of a Space Station-Based Flight Experiment for the VASIMR Magneto-Plasma Rocket

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Introduction

The Advanced Space Propulsion Laboratory at the NASA Johnson Space Center has been engaged in the development of a magneto-plasma rocket for several years ¹. This type of rocket could be used in the future to propel interplanetary spacecraft. One feature of this concept is the ability to vary its specific impulse so that it can be operated in a mode that maximizes propellant efficiency or a mode that maximizes thrust. For this reason the system is called the Variable Specific Impulse Magneto-plasma Rocket or VASIMR. This ability to vary specific impulse and thrust will allow for optimum low thrust interplanetary trajectories and results in shorter trip times than is possible with fixed specific impulse systems while preserving adequate payload margins.

In the development of the VASIMR technology, a series of ground-based experiments and space demonstrations are envisioned ². A ground-based experiment of a low-power VASIMR prototype rocket is currently underway at the Advanced Space Propulsion Laboratory. The next step is a proposal to build and fly a 25-kilowatt VASIMR rocket as an external payload on the International Space Station (ISS) as shown in Figure 1. This experiment will provide an opportunity to demonstrate the performance of the rocket in space and measure the induced environment. The experiment will also utilize the space station for its intended purpose as a laboratory with vacuum conditions that cannot be matched by any laboratory on Earth.

The VASIMR experiment will also blaze the trail for the wider application of advanced electric propulsion on the space station. An electric propulsion system like VASIMR, if provided with sufficient electrical power, could provide continuous drag force compensation for the space station. Drag compensation would eliminate the need for reboosting the station, an operation that will consume about 60 metric tons of propellant in a ten-year period. In contrast, an electric propulsion system would require as little as 300 kg of propellant per year. In fact, a system like VASIMR can use waste hydrogen from the station's life support system as its propellant. This waste hydrogen is otherwise dumped overboard. Continuous drag compensation would also improve the microgravity conditions on the station. So electric propulsion can reduce propellant delivery requirements and thereby increase available payload capacity and at the same time improve the conditions for scientific research.

The VASIMR rocket produces a plasma exhaust that can provide a conducting path between the station and the space environment. This is a beneficial effect that prevents a charge buildup on the station. The station already operates two dedicated non-propulsive plasma contactor devices for this purpose. A VASIMR rocket could function as an additional plasma contactor.

Following a successful experiment, it would be feasible to build an operational VASIMR unit that could be located on the station to provide useful thrust for drag compensation. In order to provide power for continuous thrusting, it may be necessary to augment the power generation system for the station. Another attractive possibility is to develop an electric propulsion test facility for the space station. A concept for such a test facility is shown in Figure 2. This facility could be used for testing and certifying a variety of propulsion systems at various stages of maturity while providing thrust for the space station.

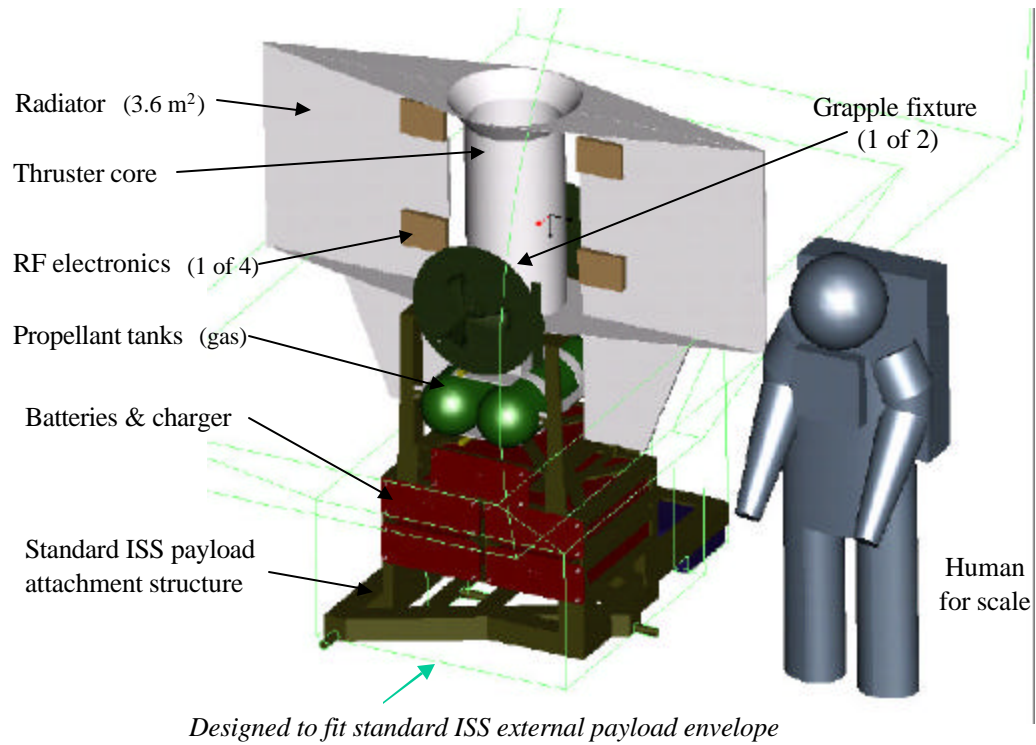


Figure 1: Preliminary design of VASIMR Experiment for the International Space Station

The flight testing of the VASIMR on the International Space Station will be an early step leading to more powerful and capable propulsion systems that will be demonstrated on free-flying spacecraft in near-Earth space and eventually on missions to the planets.

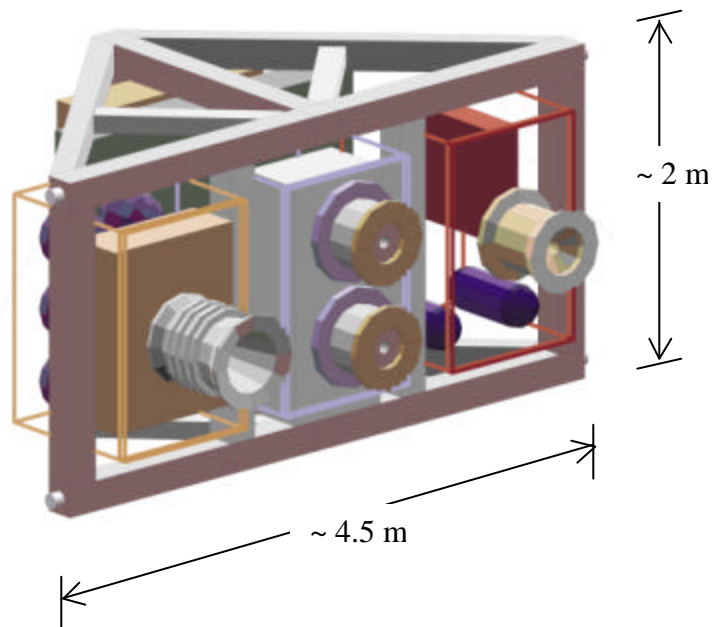


Figure 2: Concept for an International Space Station Electric Propulsion Test Facility

Objectives of Flight Experiment

The objectives of the experiment are to operate the VASIMR system in space and to collect data on its performance and its induced environment. The minimum success criteria are to operate the thruster at ten kilowatts for up to ten minutes and to operate the thruster at its full power of 24 kilowatts for at least ten seconds. The extended goal for this experiment is to operate the thruster for a ten-minute cycle at least once per day in a program lasting three to four months. The experiment is designed for at least 200 operation cycles at full power of 24 kilowatts for 10 minutes.

Preliminary Design of ISS Flight Experiment

The VASIMR flight experiment would be delivered to orbit in the Space Shuttle payload bay. It would be mounted on a standard payload attachment structure. After removal from the payload bay by the shuttle robotic arm, it would be handed to the space station robotic arm that would place it at an external payload attach site on the station truss. A mating device for power and data connections exists at the payload sites shown in Figure 3.

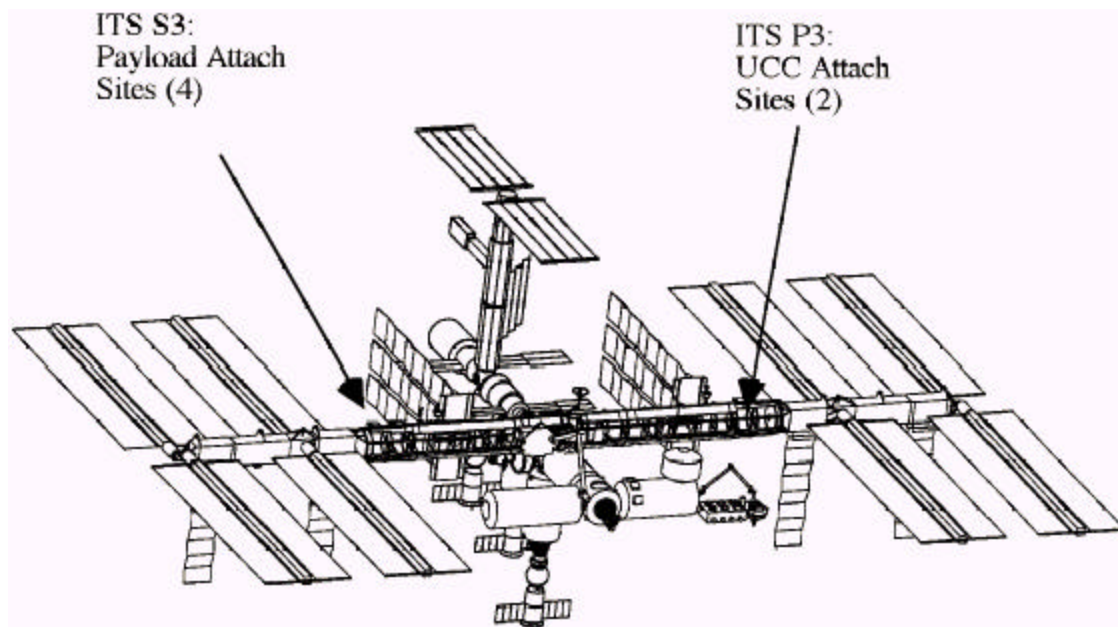


Figure 3: Payload Attachment Sites on the International Space Station

Thruster Assembly

The thruster assembly is composed of an inner tube in which the neutral propellant is injected and ionized and a larger tube, which supports the radio frequency antennas, which ionize the gas and heat the plasma. Electromagnet coils surrounding these tubes provide the magnetic field to constrain the flow of the plasma and form the magnetic nozzle. High temperature superconducting magnets will be used. At full power of 24 kilowatts, the thruster will be able to generate a thrust of 0.5 N at a low specific impulse of 4,500 seconds and a thrust of 0.2 N at a higher specific impulse of 10,00 seconds. It will be possible to vary the thrust and specific impulse over that range and to operate at lower power levels if desired. A more detailed explanation of the thruster is provided in the references.

Propellant Supply

Although the VASIMR could operate with waste hydrogen gas from the space station, no connections to this supply are planned for the experiment. The experiment will carry two dedicated propellant tanks which each have the capacity to store all the propellant needed for an experimental program lasting several months. With two propellant tanks, the opportunity exists to perform experiments with more than one type of propellant. Hydrogen is the primary choice for propellant but deuterium and helium are also of interest and might also be included. All the propellant is stored and used in gaseous form at ambient temperature. Each cylindrical tank has a length of 78 cm. and a diameter of 25 cm. Propellant will be stored at an initial pressure of 3600 psi. The duration of thruster operation possible with the capacity of both tanks is provided in Table 1.

Table 1: Duration with Two Propellant Tanks

Propellant	5 mg/sec (4500 sec Isp)	2 mg/sec (10000 sec Isp)
Hydrogen	52 hours	132 hours
Deuterium	106 hours	264 hours
Helium	108 hours	270 hours

Power Supply

The experiment would receive one to three kilowatts of power from the Space Station. About 600 watts would be used for cryogenic cooling and control devices. Additional power would be stored in a set of batteries. The battery system is composed of nickel-cadmium cells arranged in four modules. Each module can provide 1.92 kilowatt-hours of power, has dimensions of 64 cm. by 41 cm. by 17 cm. and a mass of 75 kg. The total mass of four battery modules, two charging units and cabling is 540 kg.

The batteries are designed to provide 24 kilowatts of power for up to ten minutes when fully charged. The VASIMR experiment would be operated for short periods when the batteries can provide power to the amplifiers that feed radio-frequency power to the thruster assembly.

Thermal Control

Thermal control is the most significant engineering challenge in the design of the flight version of the rocket. The superconducting electromagnets will need to be maintained at cryogenic temperatures in order to operate properly. The magnet is in close proximity to the plasma so a combination of compact insulation and passive and active heat transport techniques will be employed. Parts of the thruster core and radiator surfaces are made of highly conductive material. Heat from the thruster core is passively conducted to the radiators. Integral phase-change material made of wax absorbs excess heat during thruster operation and dissipates the heat during the long periods when the thruster is not operating. The use of this heat sink material allows for smaller radiator surfaces. Heat pipes are employed in high temperature areas such as the antennas to transport heat efficiently to the radiator surfaces. The amplifier electronics are mounted on the radiator surfaces for direct heat dissipation.

Command and Control

The experiment will be designed to allow for operation and data collection either from onboard the Space Station or from the ground. Commands and data will pass through one of two Universal Mini-Controllers mounted on the experiment to the Space Station data management system. The Universal Mini-Controller is a compact, generic control system being developed at the Johnson Space Center for a variety of applications. There will be a variety of diagnostic instruments installed on the experiment to monitor its performance and the environment surrounding the thruster. A diagram of the command and control system is provided in Figure 4.

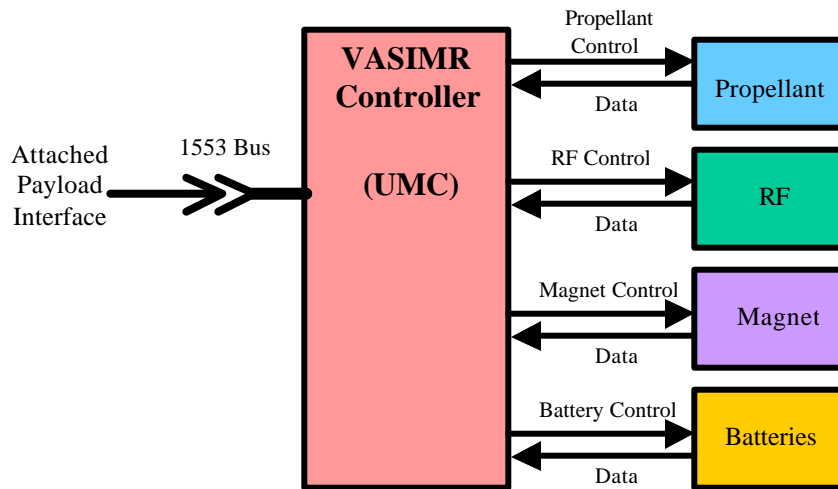


Figure 4: Command and Control System Schematic for the VASIMR Experiment

Mass Properties

The mass of each major system and total mass are shown in Figure5. As indicated in the graph, the power storage system represents the largest portion of the overall mass.

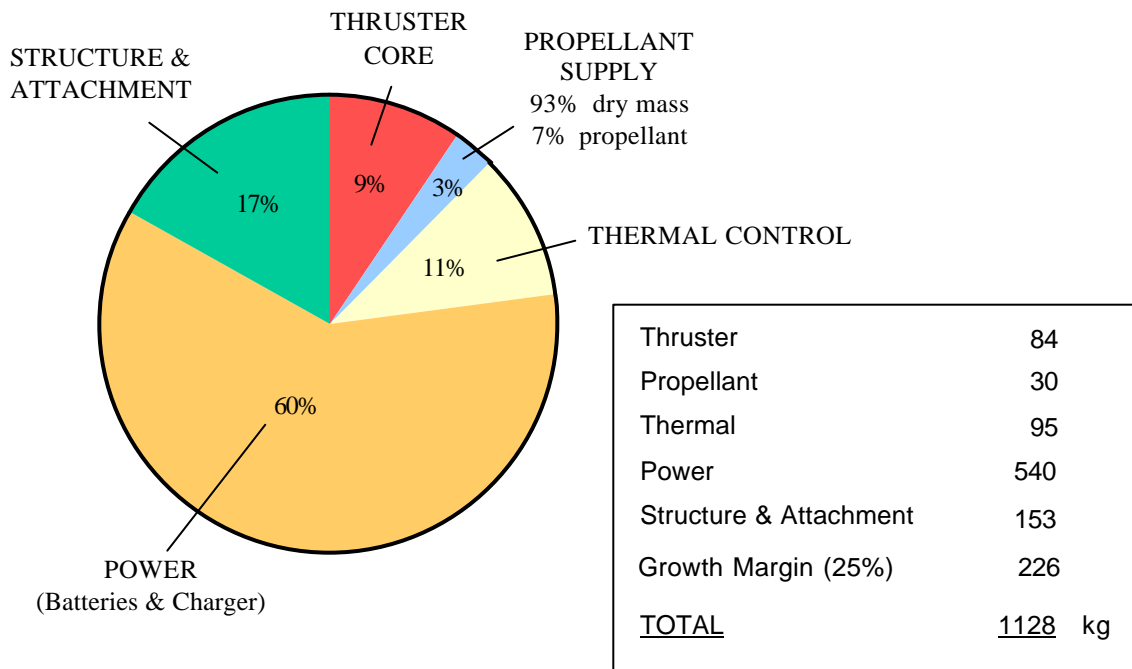


Figure 5: Mass of VASIMR Experiment on the ISS

Servicing

The experiment will be designed for delivery, deployment, and operation with no extra-vehicular activity requirements. However, provisions will be included to capitalize on the presence of humans in case repairs or servicing is required. The batteries, propellant tanks, and electronic components will be designed for on-orbit removal and replacement, if necessary.

Component Development and Status

Thruster Core: Extensive experimentation is underway at the Advanced Space Propulsion Laboratory to characterize and refine the design of the basic VASIMR thruster. Detailed temperature measurements are being taken to help define the thermal loads.

High-Temperature Superconducting Magnet: A prototype of a flight-like superconducting magnet has been fabricated and is currently undergoing testing. The magnet has been cooled to the superconducting range. The magnet will be operated at approximately 40 degrees K

Propellant Supply: The propellant tanks proposed for this demonstration are existing tanks that were developed for the Space Shuttle Manned Maneuvering Unit program. A number of surplus flight-certified tanks are in storage at the Johnson Space Center and would be available for use.

Power System: The nickel-cadmium batteries and the battery charging unit proposed for this demonstration are based on a mature design developed for the X-38 flight vehicle program at the Johnson Space Center. There is also a possibility of using slightly less mature lithium battery technology that would result in greatly reduced size and mass for the system.

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References

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2. A.J. Petro, et.al, "A Flight Demonstration of Plasma Rocket Propulsion", 36th Joint Propulsion Conference, Huntsville, AL, 17 July 2001.